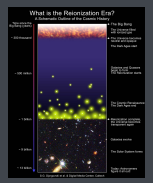
27.06.2013
IGM workshop
Edingburgh

The Helium Reionization Epoch

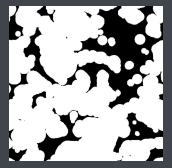
Keri Dixon

Steve Furlanetto, Andrei Mesinger

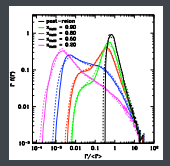
What to look forward to…



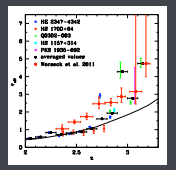
Background material



Efficient simulations of large-scale structure



Fluctuations in the He-ionizing background



Interpreting the HeII observations

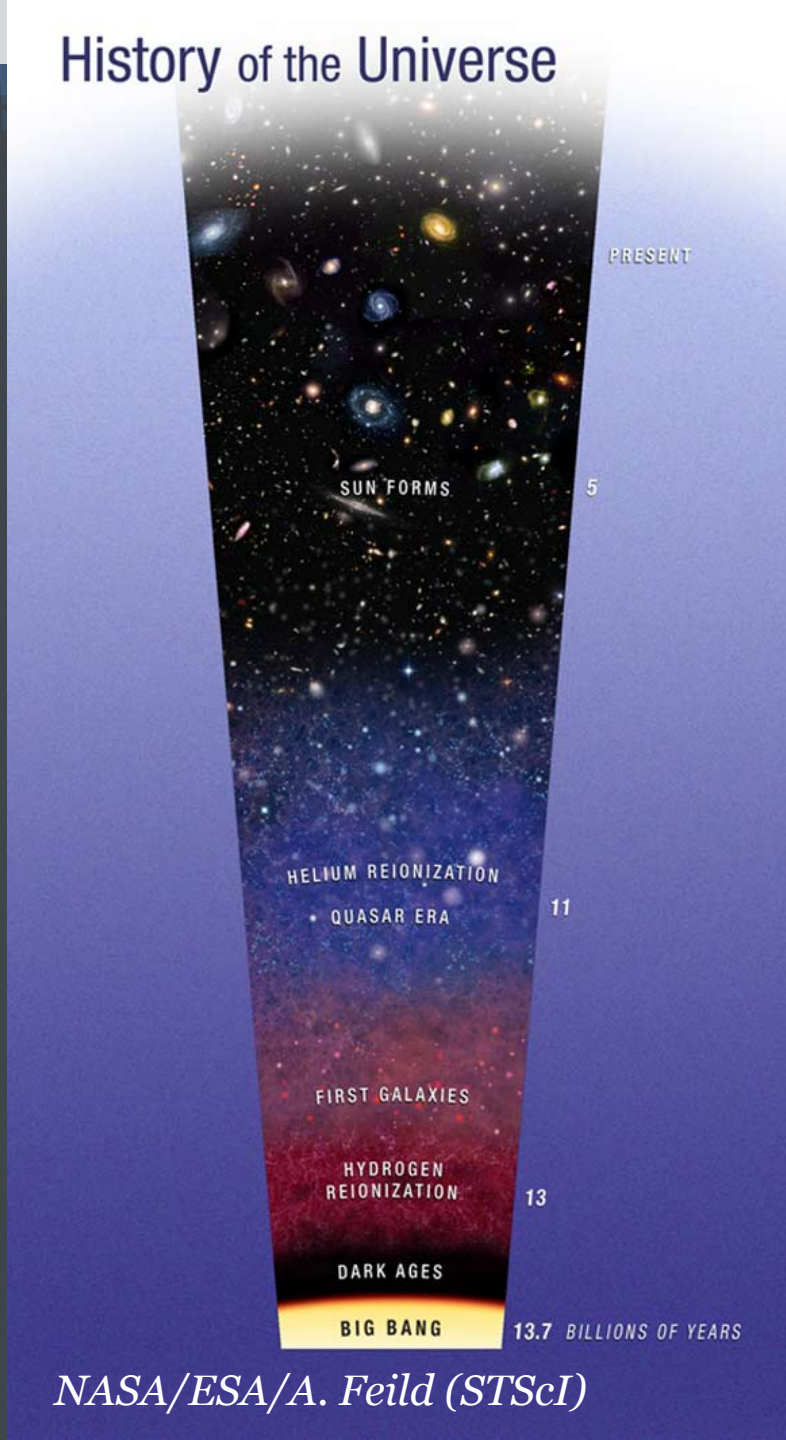
Why care about helium reionization?

Plenty of helium

~Doubles the IGM temperature

Increases mean free path of EUV photons

Learn about quasars



NASA/ESA/A. Feild (STScI)

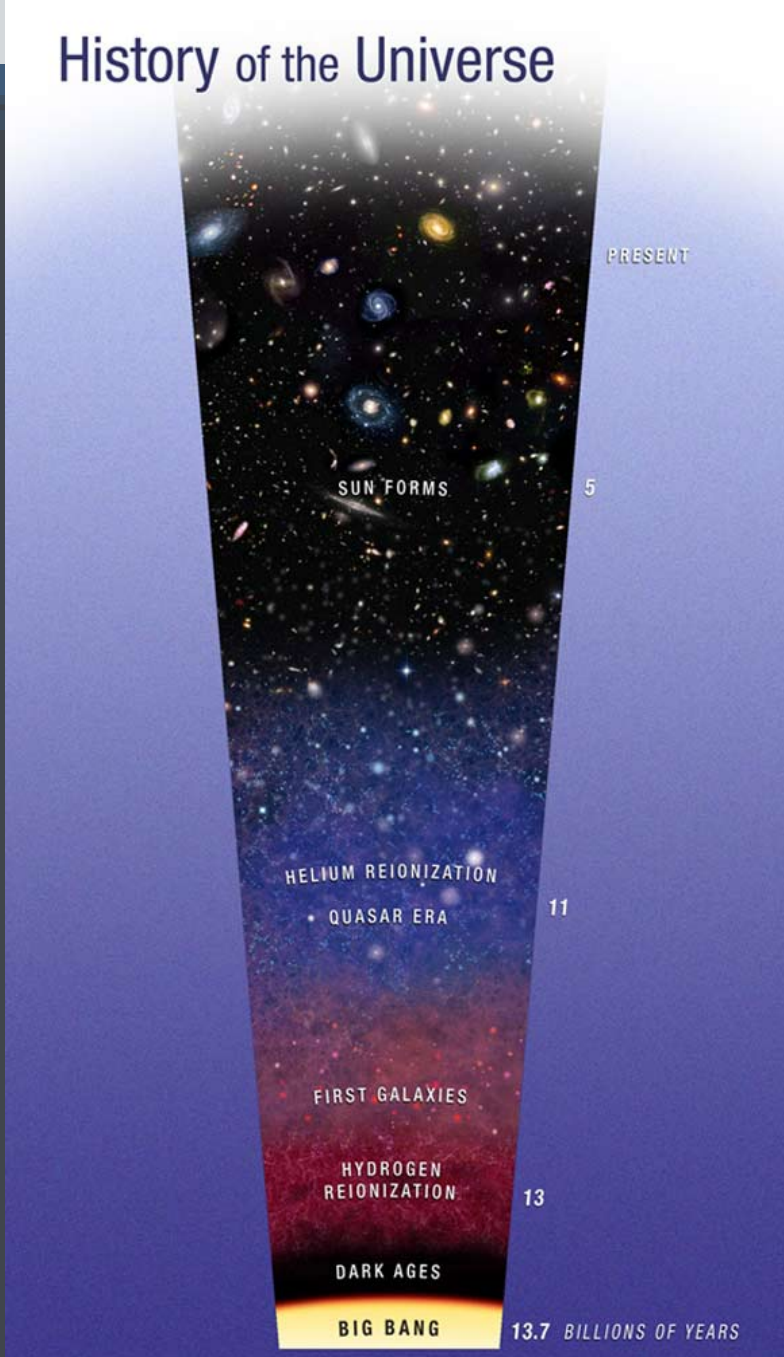
The advantages of helium

The action is lower redshift

Better understanding of IGM

Know more about quasars

COS to directly observe this epoch



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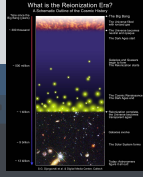


The advantages of helium

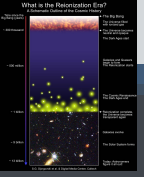
The action is lower redshift

Better understanding of IGM

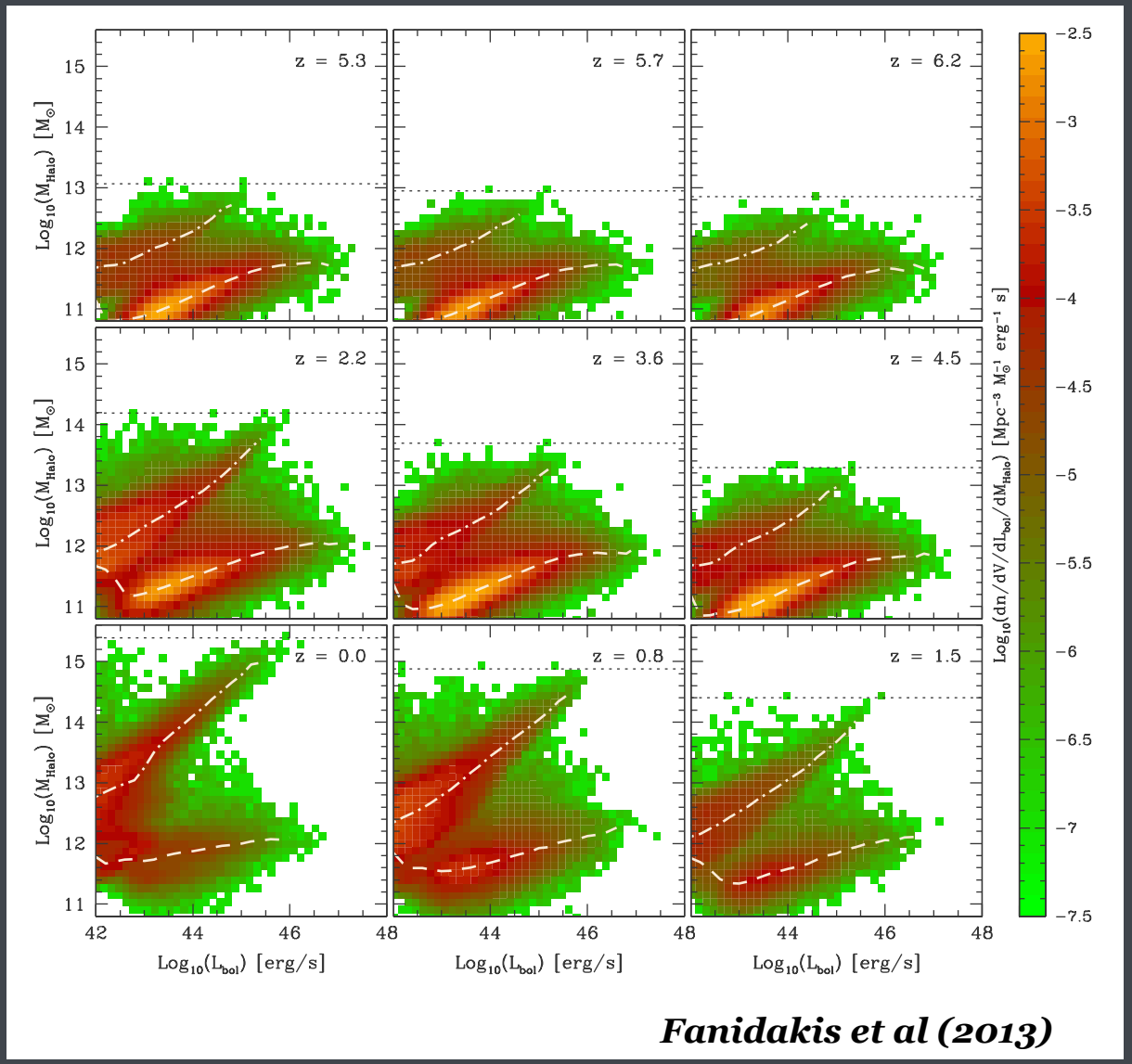
Sources + environment = no problem, right?

Know more about quasars

COS to directly observe this epoch

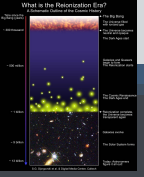


Quasars live in ~10^{12} $M_\odot$ halos



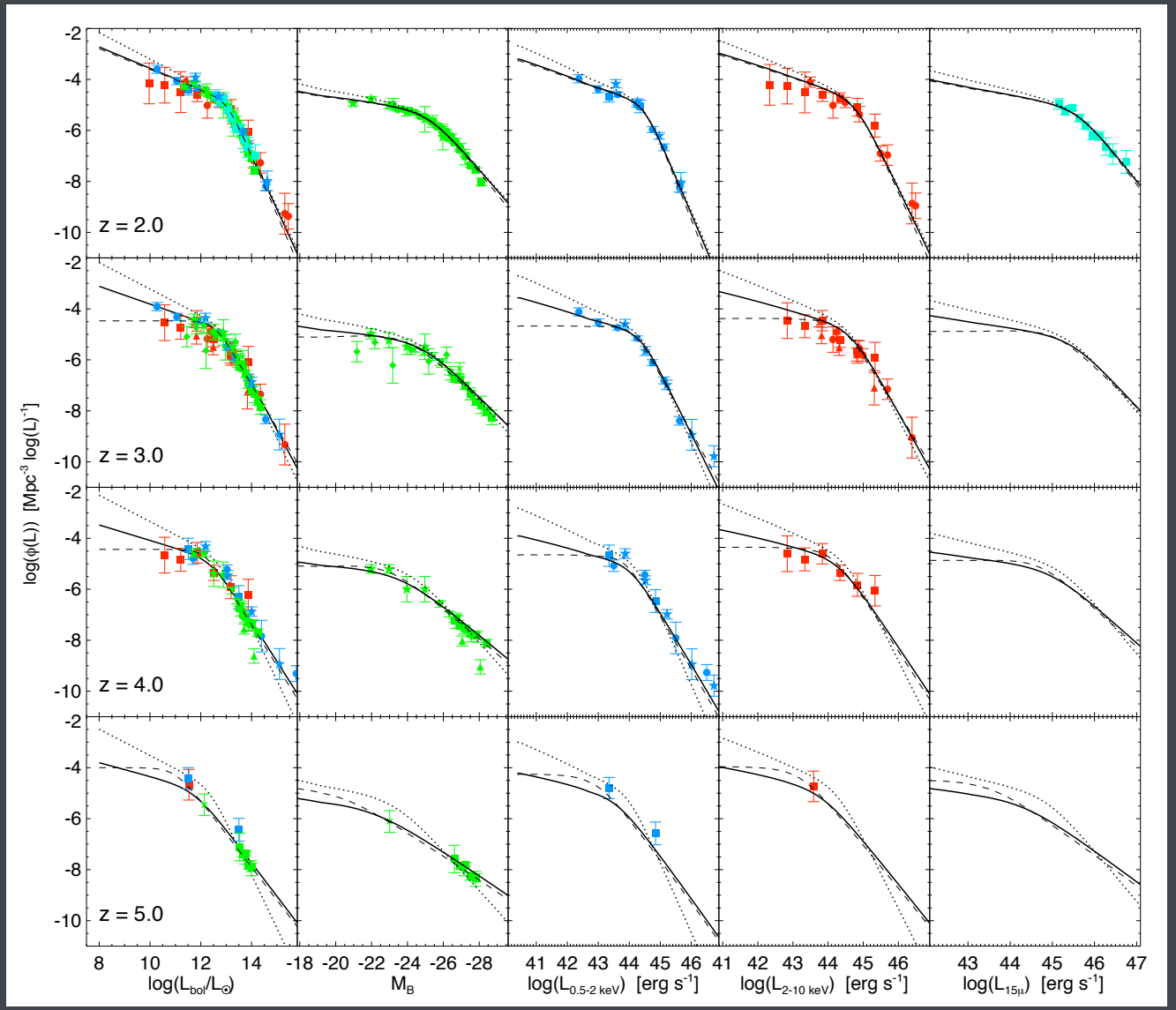
Fanidakis et al (2013)

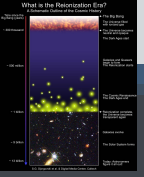
See also observations



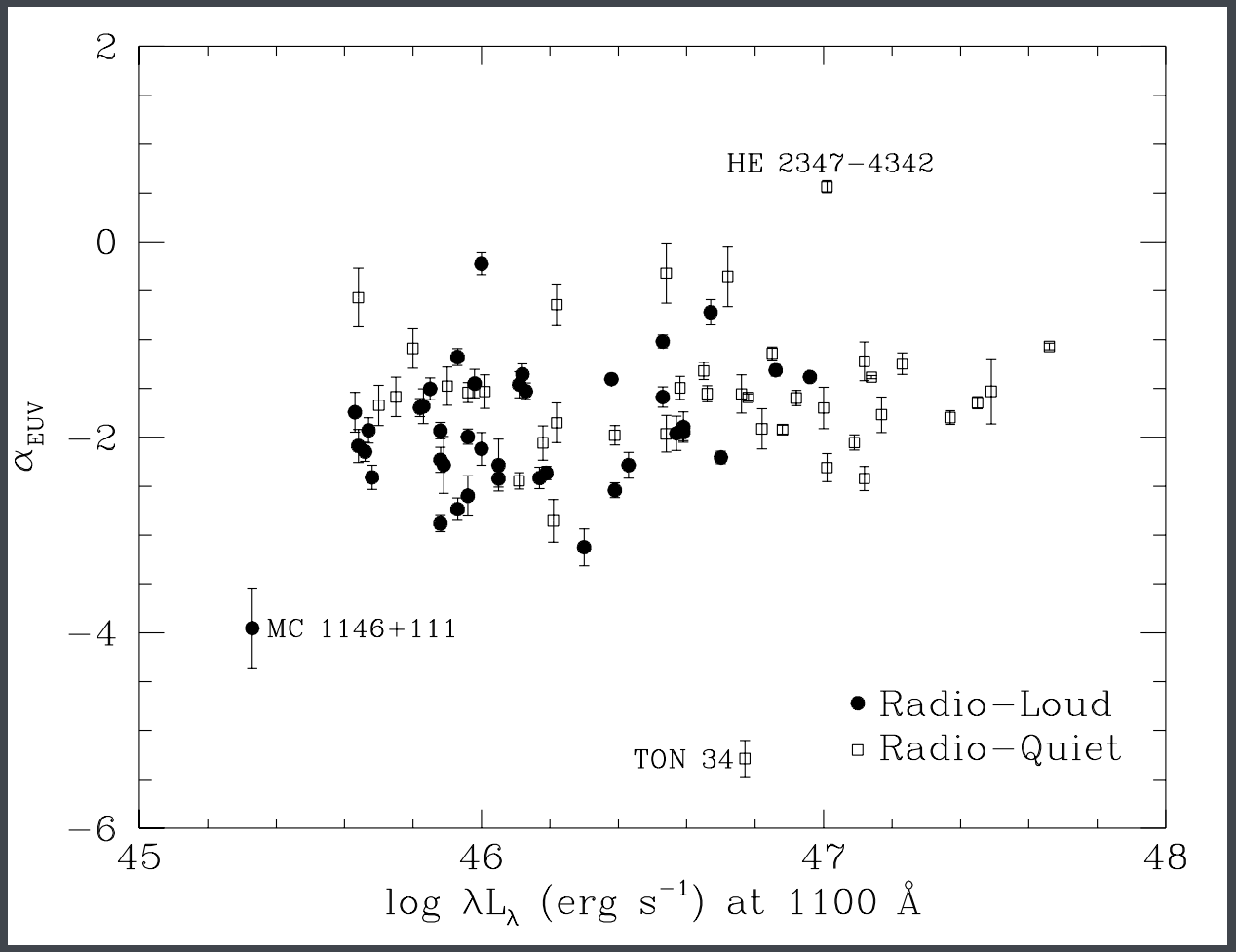
How much light?

Hopkins et al (2007)



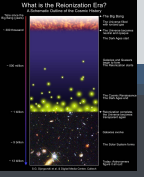


Quasars have range of α



Exact shape of power law?

Telfer et al (2002)

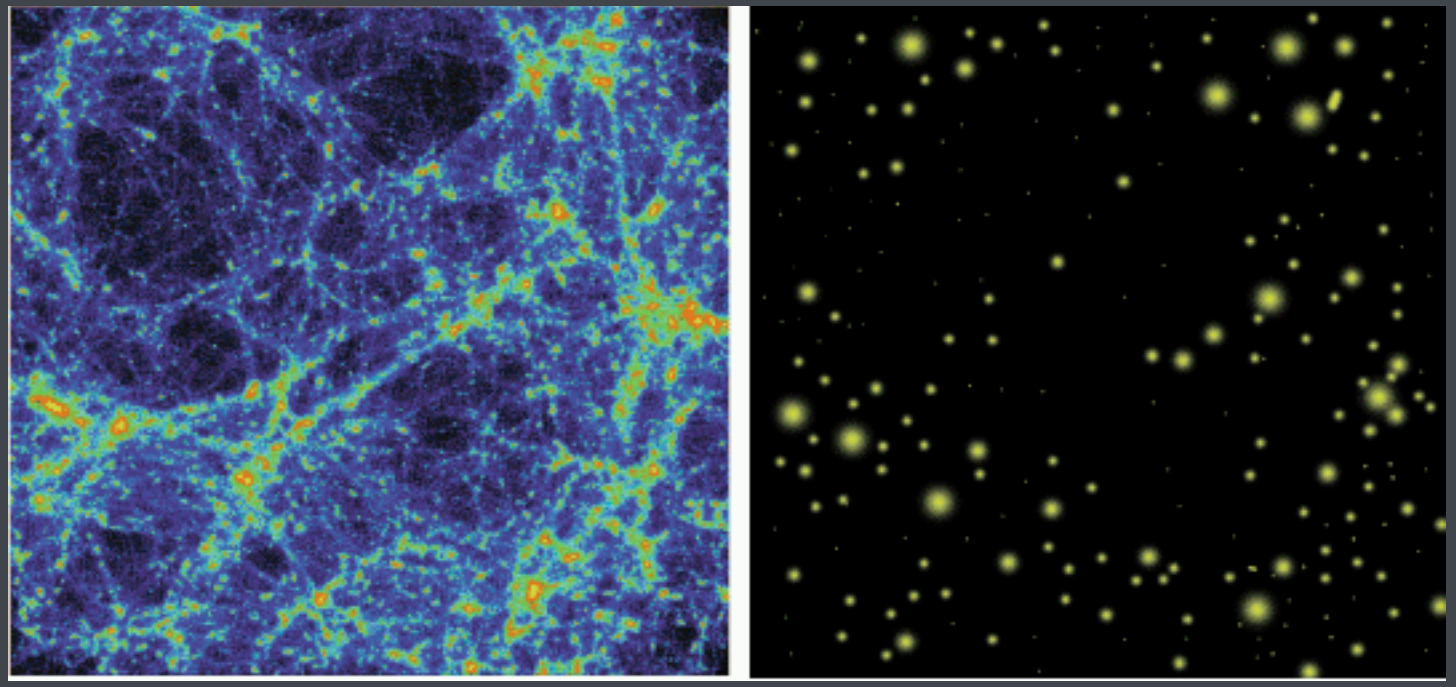


How far does this light go?

Need the mean free path, which is difficult. See every other talk this week.

Efficient methods for large-scale structure and helium reionization

Replace complexity with simplicity



Cooray, Sheth (2002)

(1) Create initial linear density and velocity fields

(2) Filter halo using the excursion-set formalism

(3) Adjust halo locations using their linear-order displacements

Find the dark matter halos

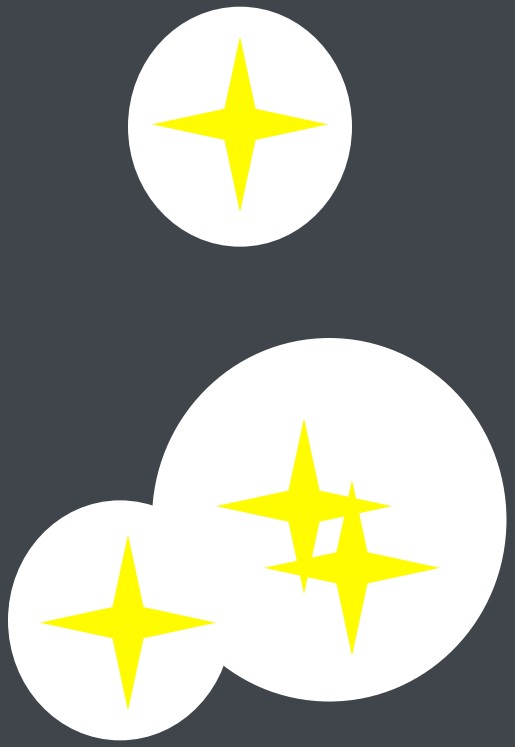
Mesinger, Furlanetto (2007)

Based DexM for HI reionization

Adjust parameters to match *N*-body simulations at $z = 3$

Fast and efficient

Find the ionization field



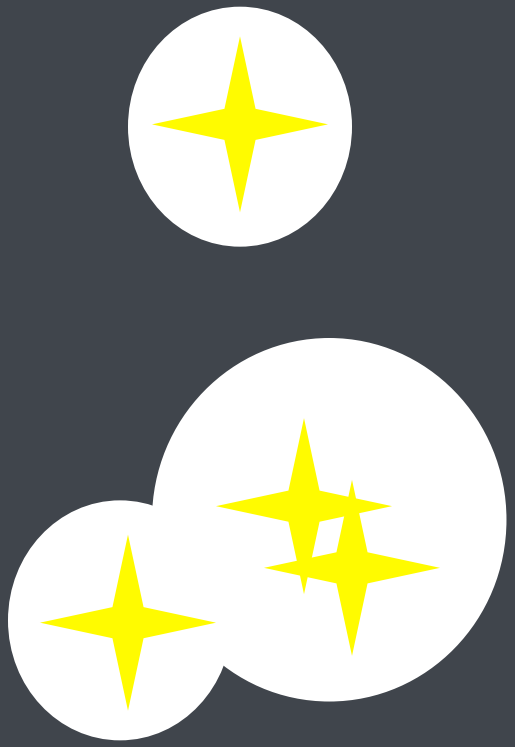
Draw ionized spheres around the halos

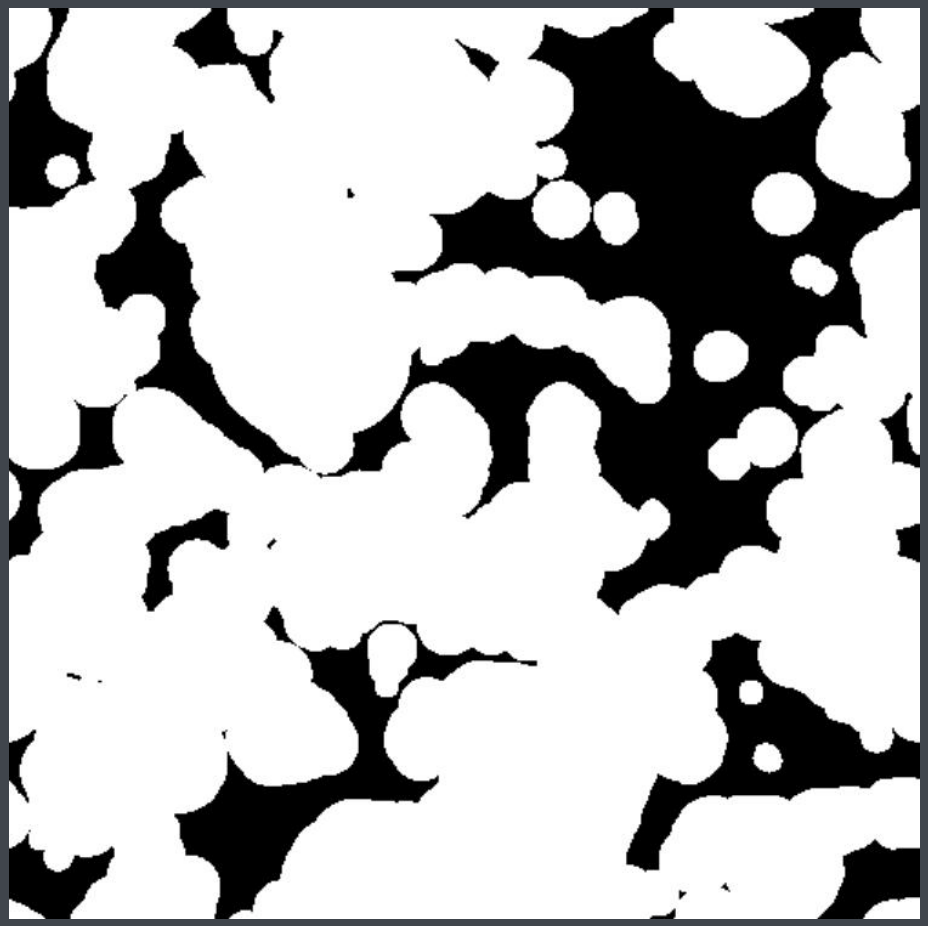
Essentially, the number of ionizing photons > HeII atoms

Flexibility to vary the ionizing-source model

Size of bubbles depends on number density of hosts

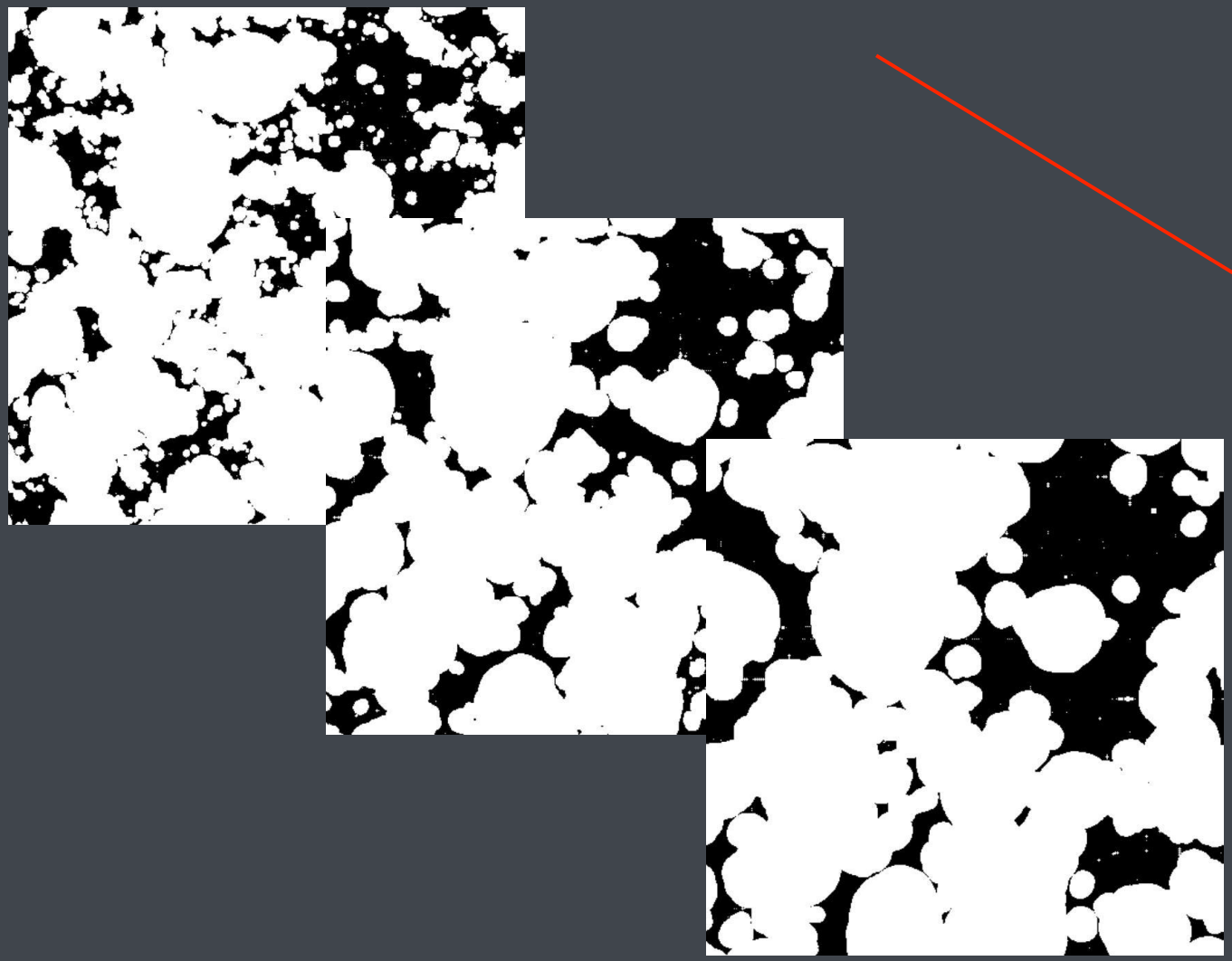
x_{HeIII} = 80%





250 Mpc

As per earlier in my talk, we checked a few models



M_{host}

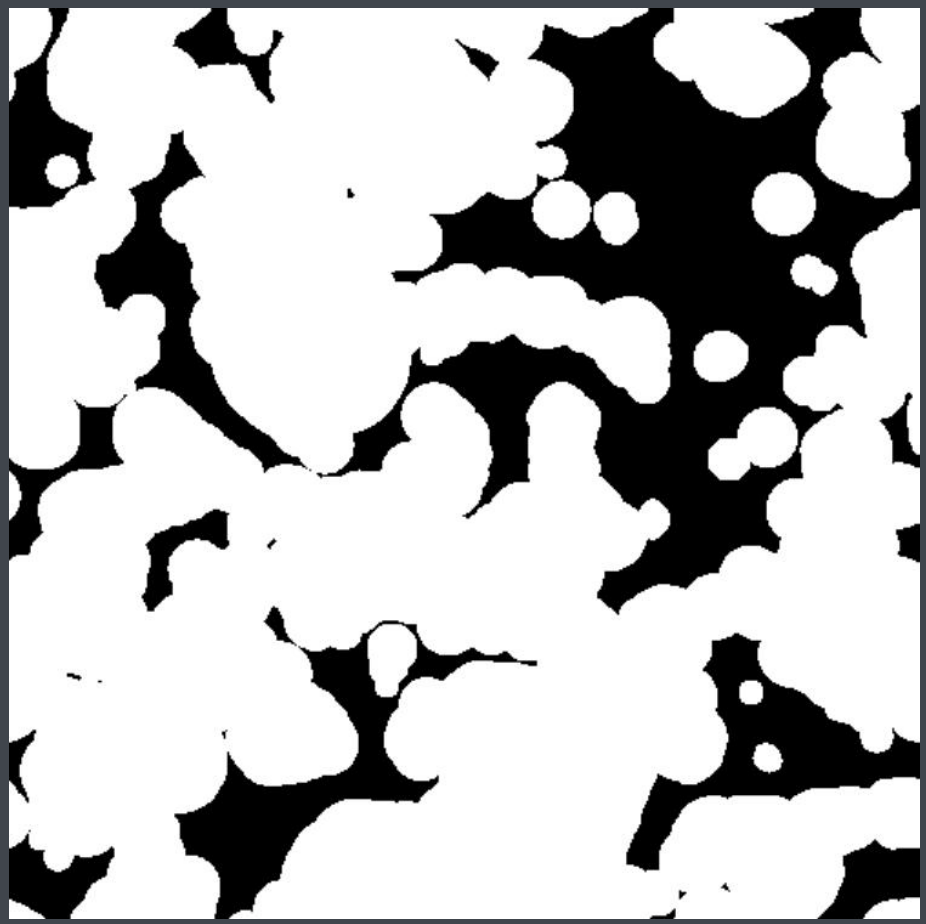
Active quasars – empirical approach

Find the number of quasars from QLF

Hopkins et al. (2007)

Randomly sample QLF to get luminosity

Place in random halo above mass threshold



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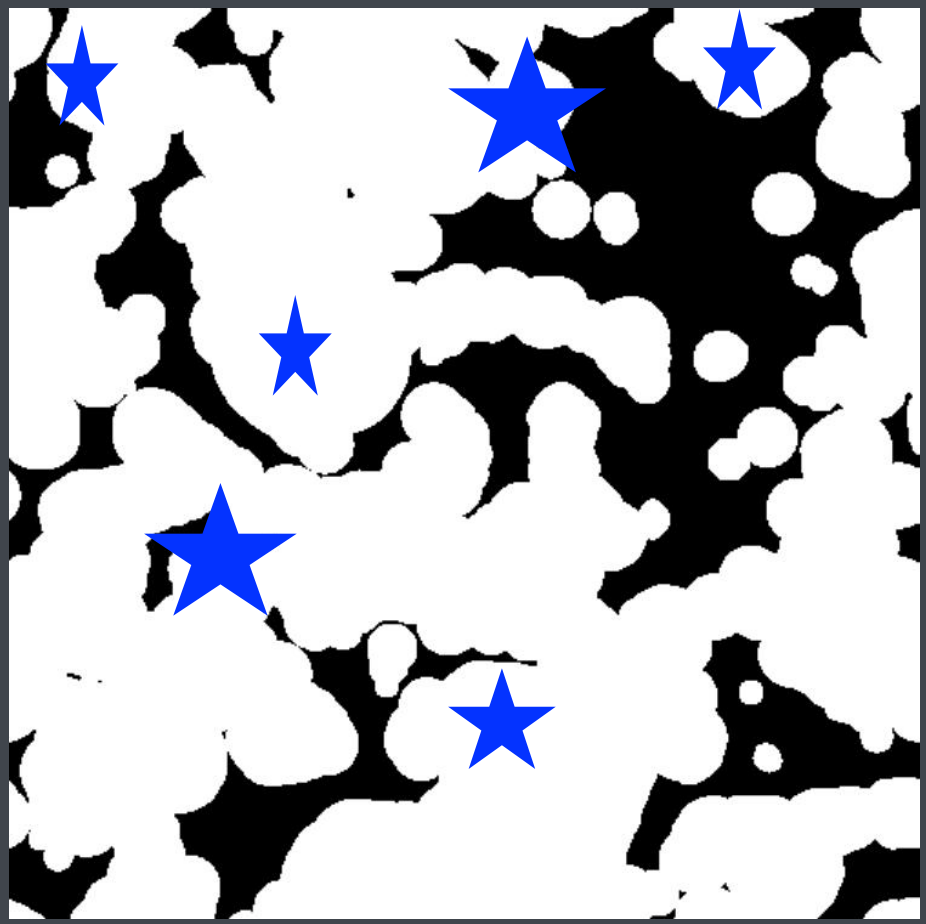

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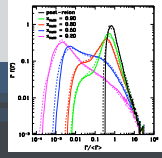
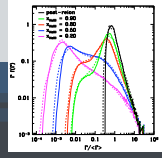


Calculate the HeII photoionization rate distribution

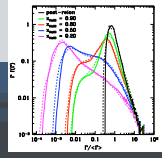


Calculating the photoionization rate

Add up the specific intensity from each quasar, using a frequency-dependent mean free path

$$J = \sum_i \frac{L_i}{(4\pi r_i^2)} e^{-r_i/\lambda_{\rm mfp}}$$

$$\lambda_{\rm mfp} = 60 \left(\frac{\nu}{\nu_{\rm HeII}} \right)^{1.5} \ {\rm Mpc}$$



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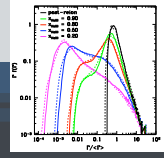
Integrate the usual over all frequencies above $\nu_{\rm min}$

$$\Gamma = 4\pi \int_{\nu_{\rm min}}^{\infty} \frac{J\sigma}{h\nu} d\nu$$



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Integrate the usual over all frequencies above ν_{min}

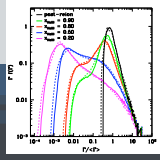
$$\Gamma = 4\pi \int_{\nu_{\rm min}}^{\infty} \frac{J\sigma}{h\nu} d\nu$$

post-reionization:

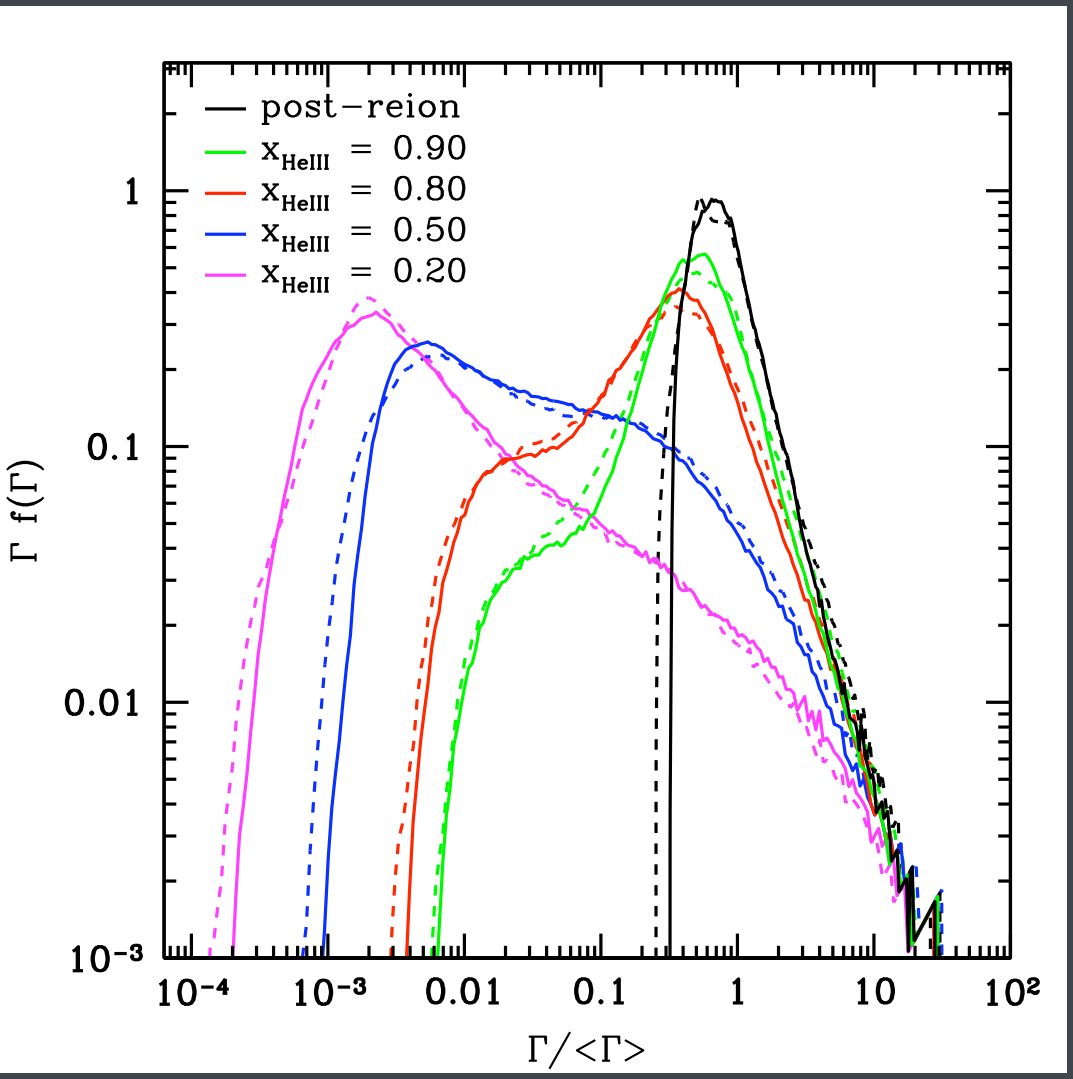
$$\nu_{\rm min} = \nu_{\rm HeII}$$

during: $\tau(\nu_{min}) = 1$

$$\nu_{\rm min} > \nu_{\rm HeII}$$



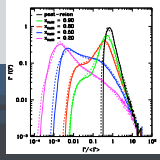
Photoionization rate distribution



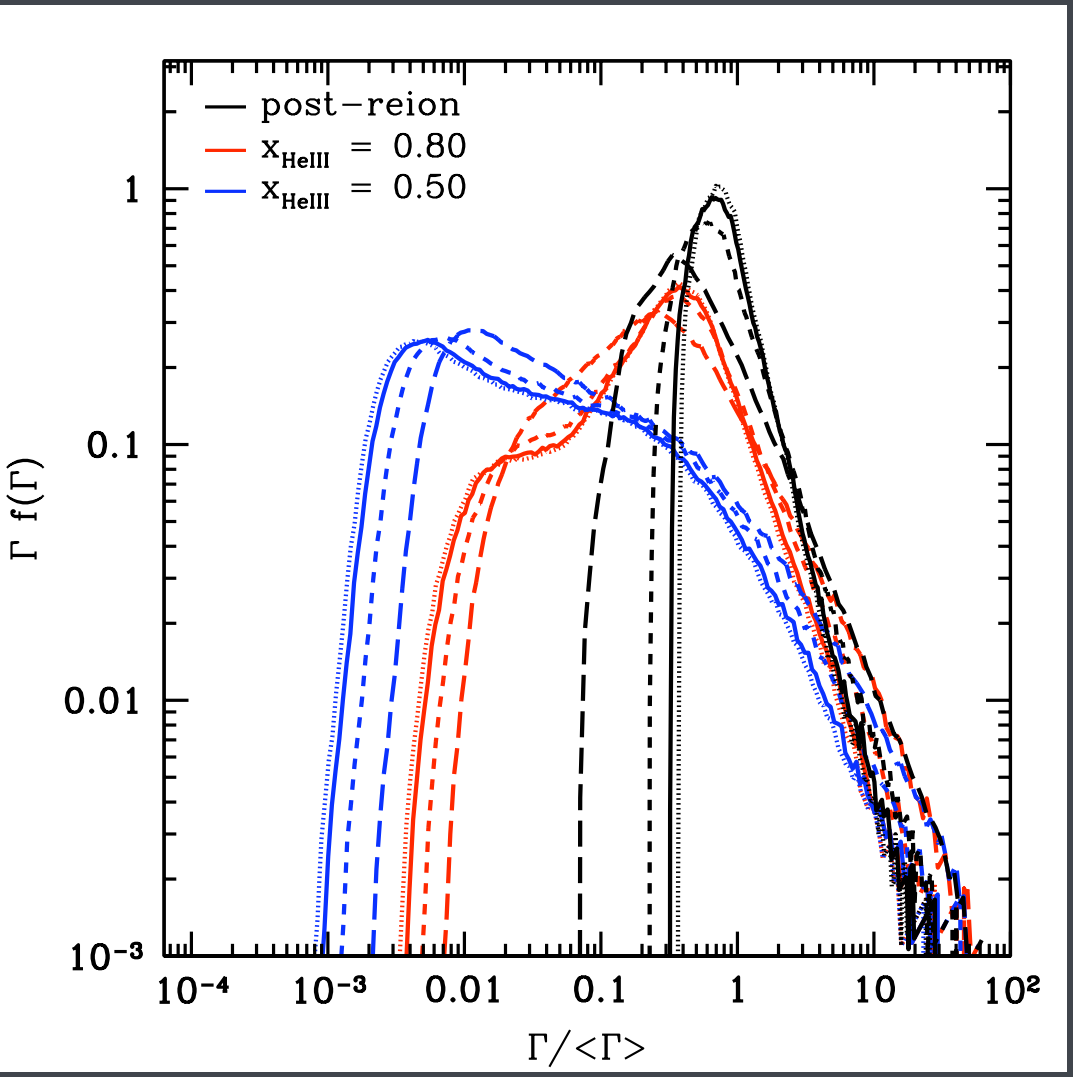
Post-reionization is narrow and nearly analytic

Bimodal during reionization

By x_{HeII} = 0.50, low Γ from high-ν photons dominates



Mean free path matters most

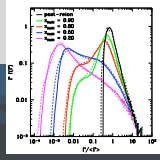


Wide → narrow:

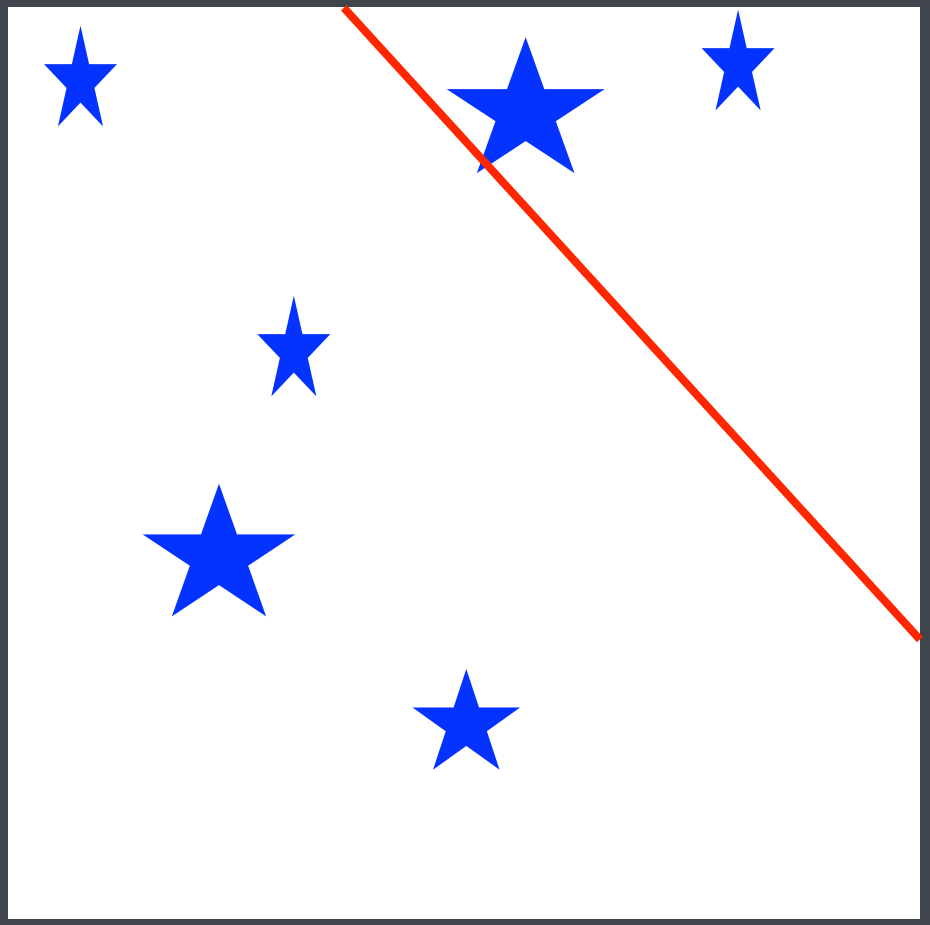
λ_{mfp} 15 → 80

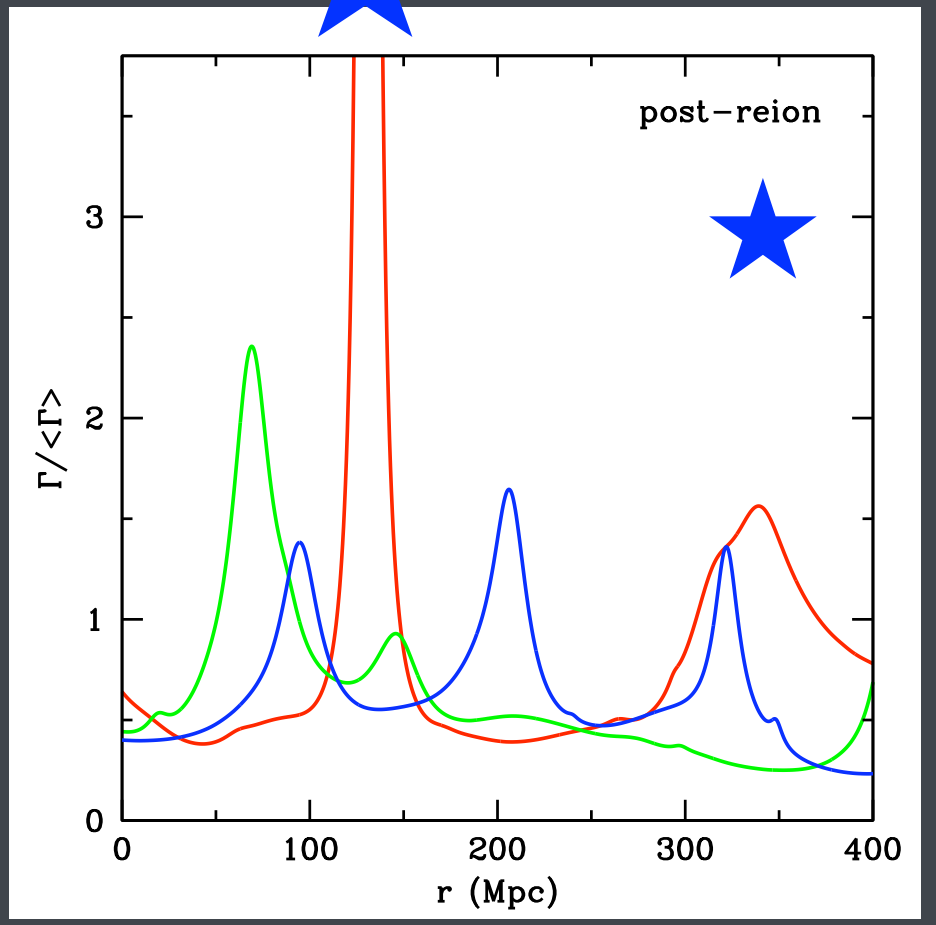
Maybe also QLF

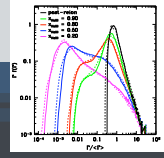
KD, Furlanetto, Mesinger (2013)



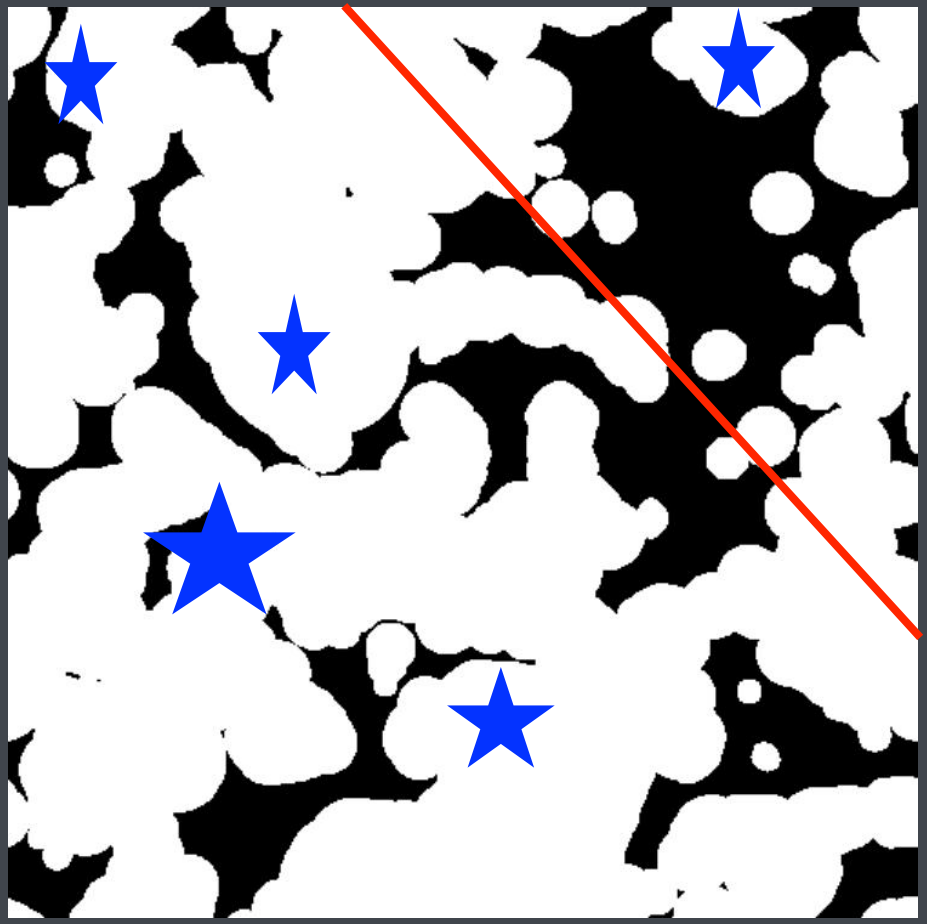
Post-reionization

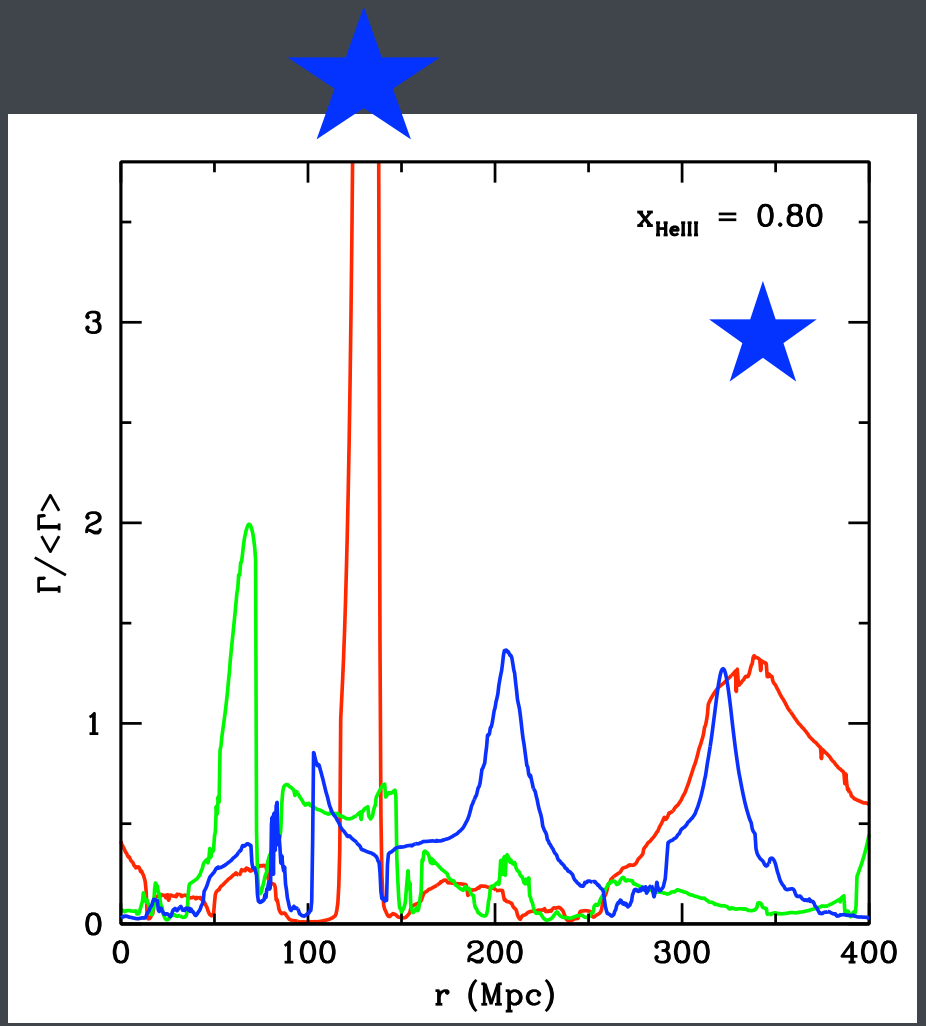


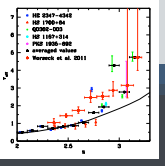




80% ionized

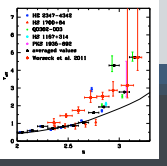




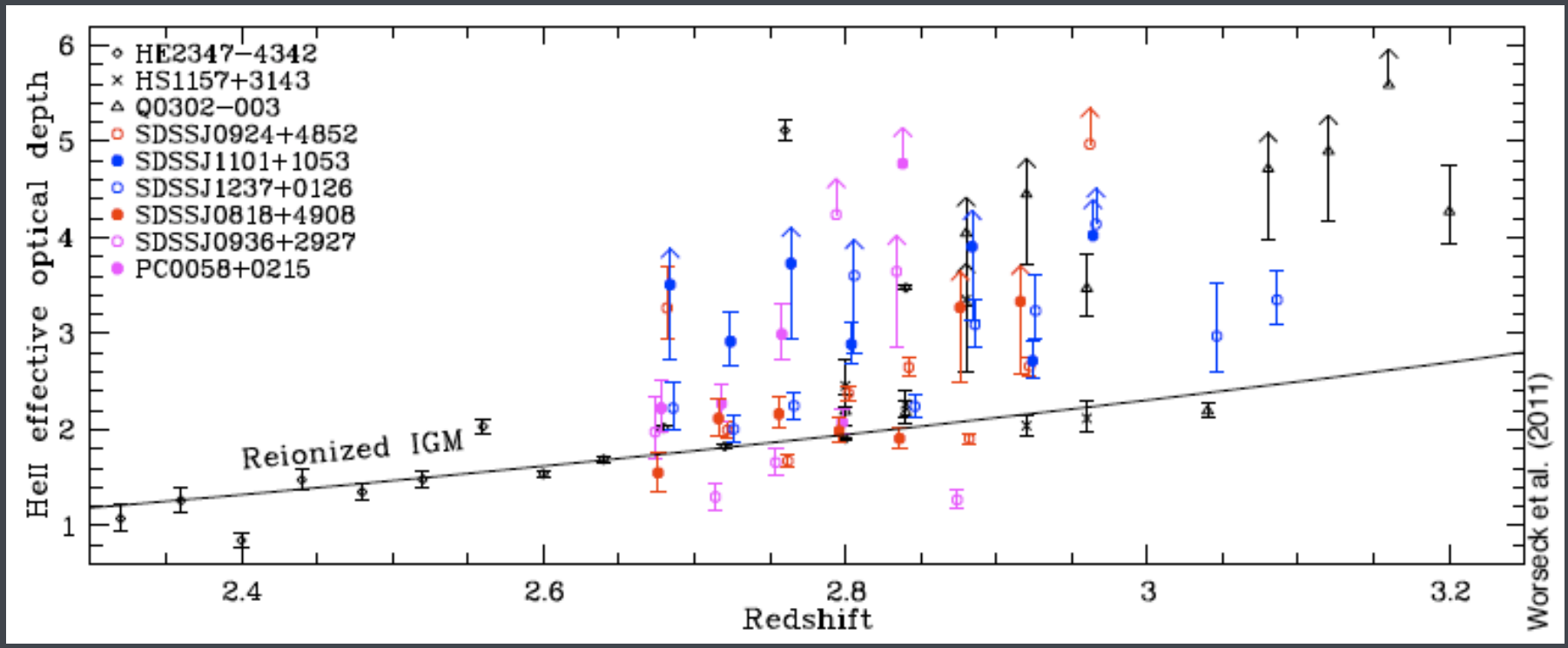


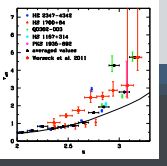
What can we learn from observations during this era?

HeII optical depth

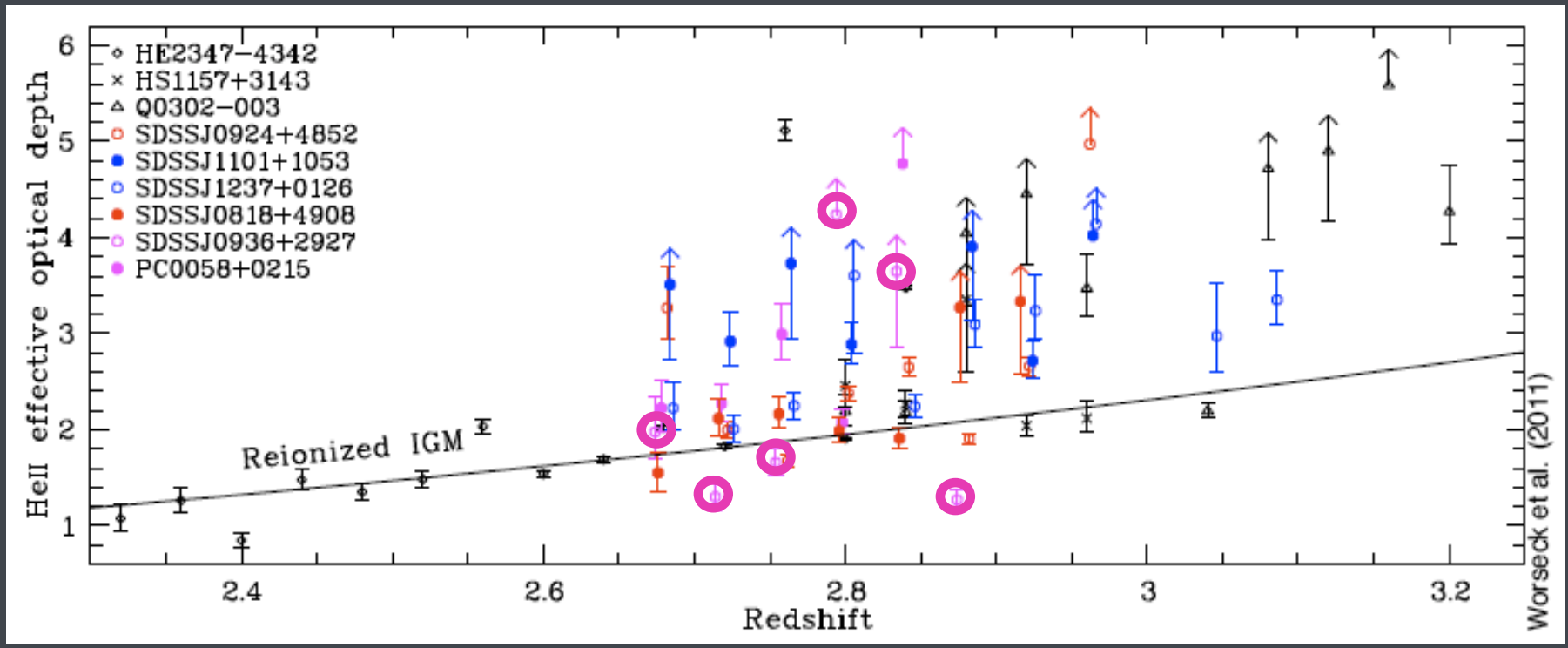


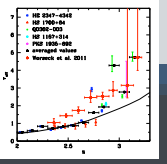
Not-so-recent COS measurements



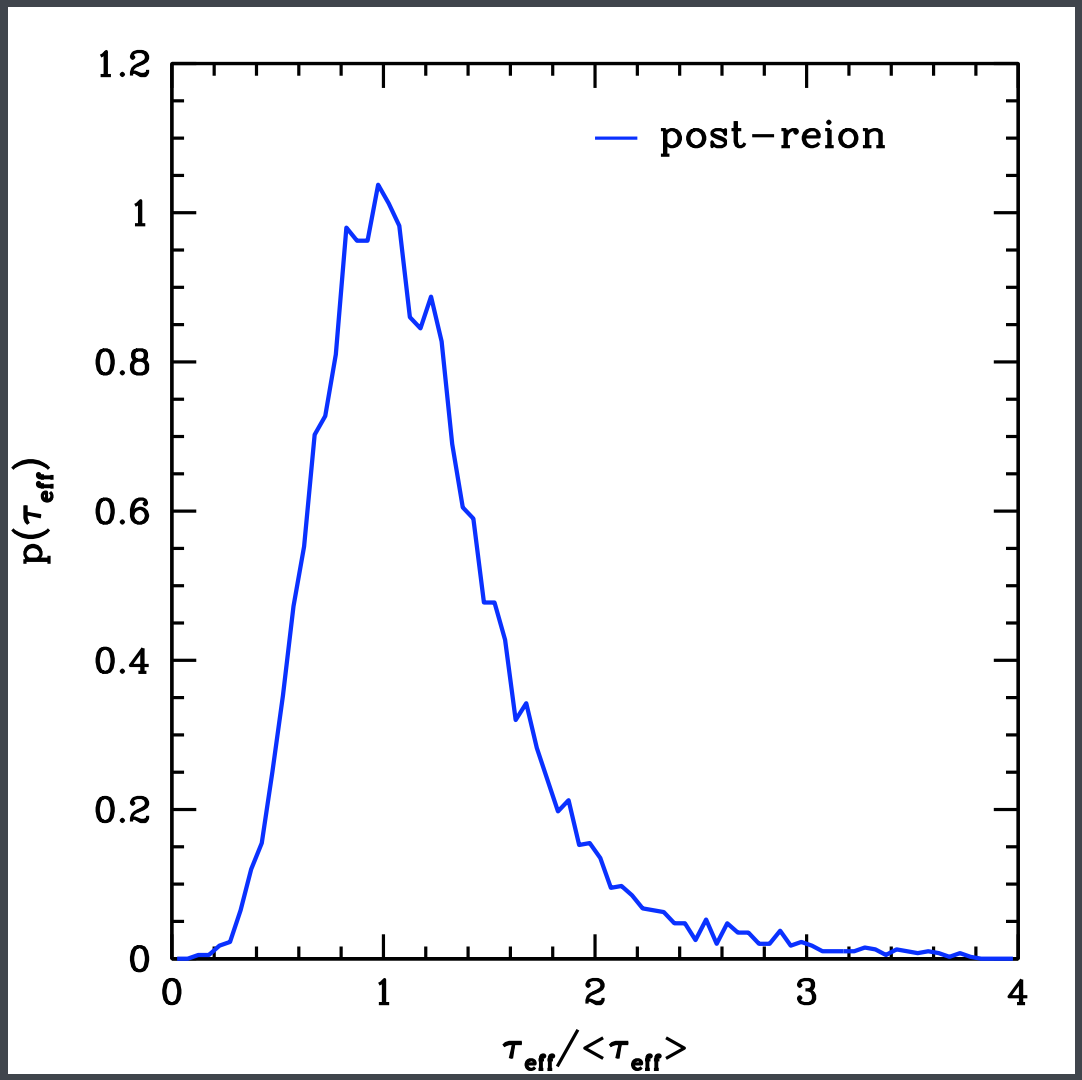


Large variations along LOS



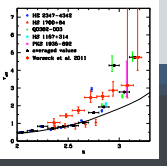


Post-reionization

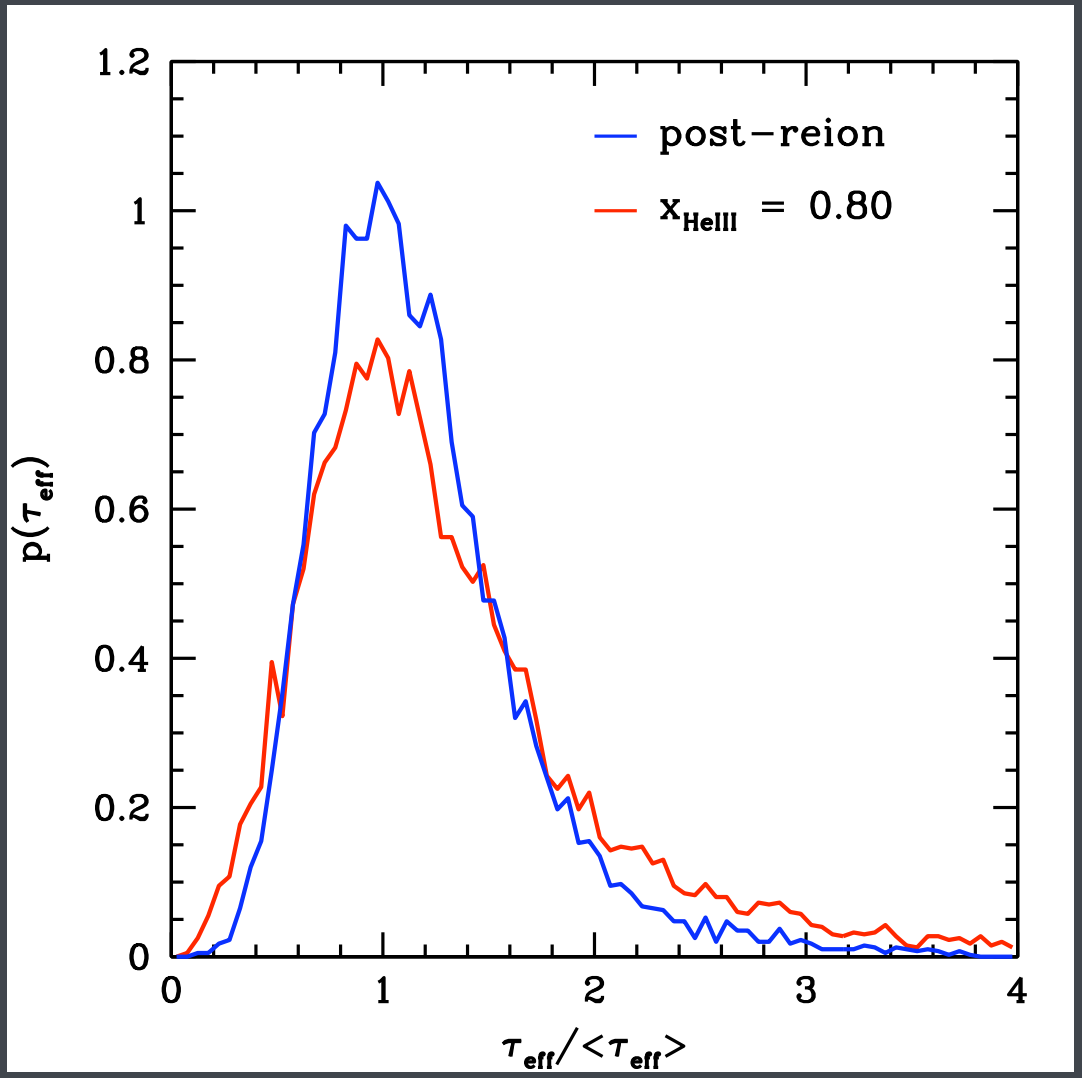


$$\tau \propto \frac{\Delta^2}{\Gamma}$$

$$\langle \tau_{\mathrm{eff}} \rangle = 2$$



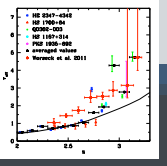
80% ionized



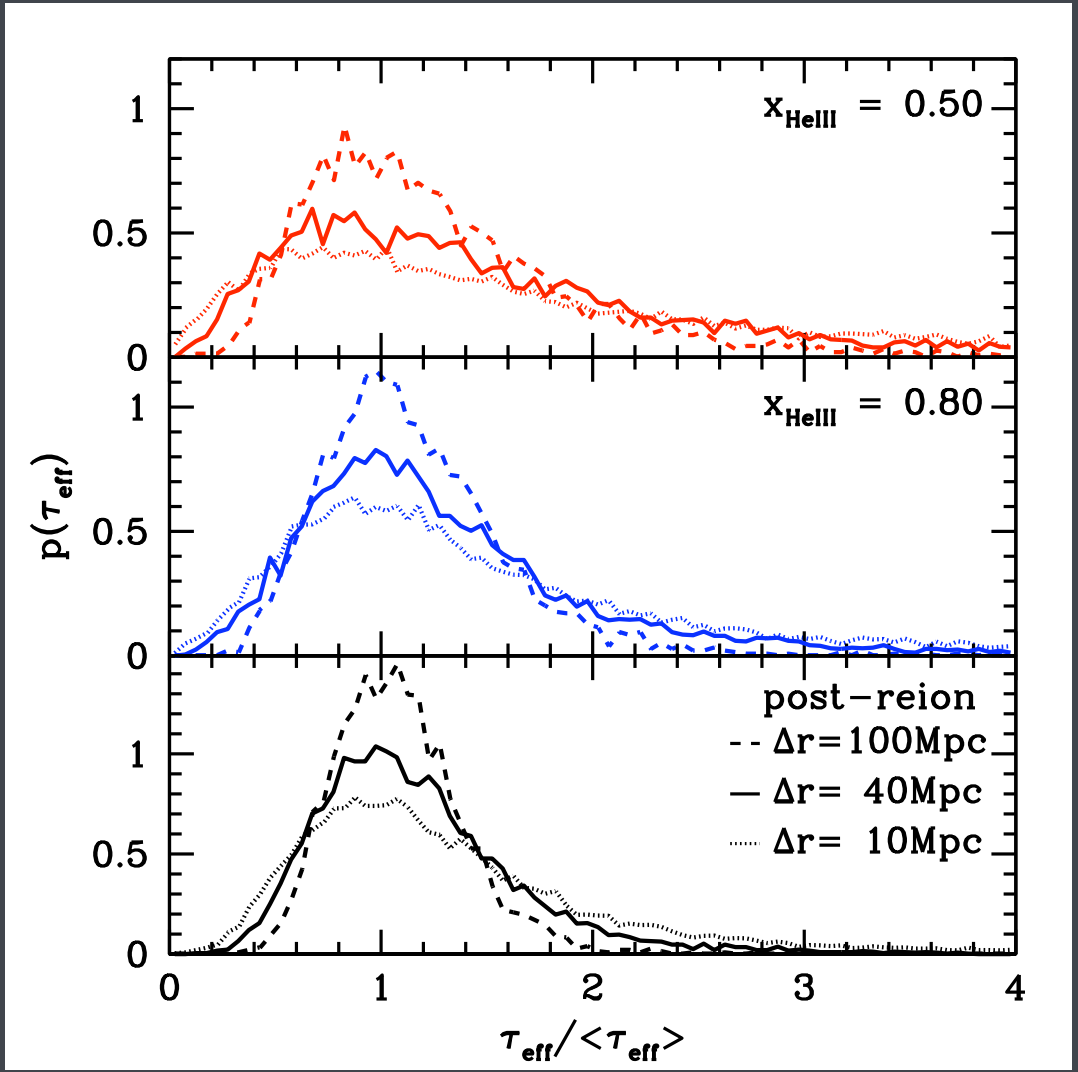
Significant spread post-reionization

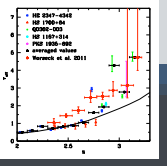
Substantial tail at high τ develops at lower x_{HeIII}

Low τ also more likely

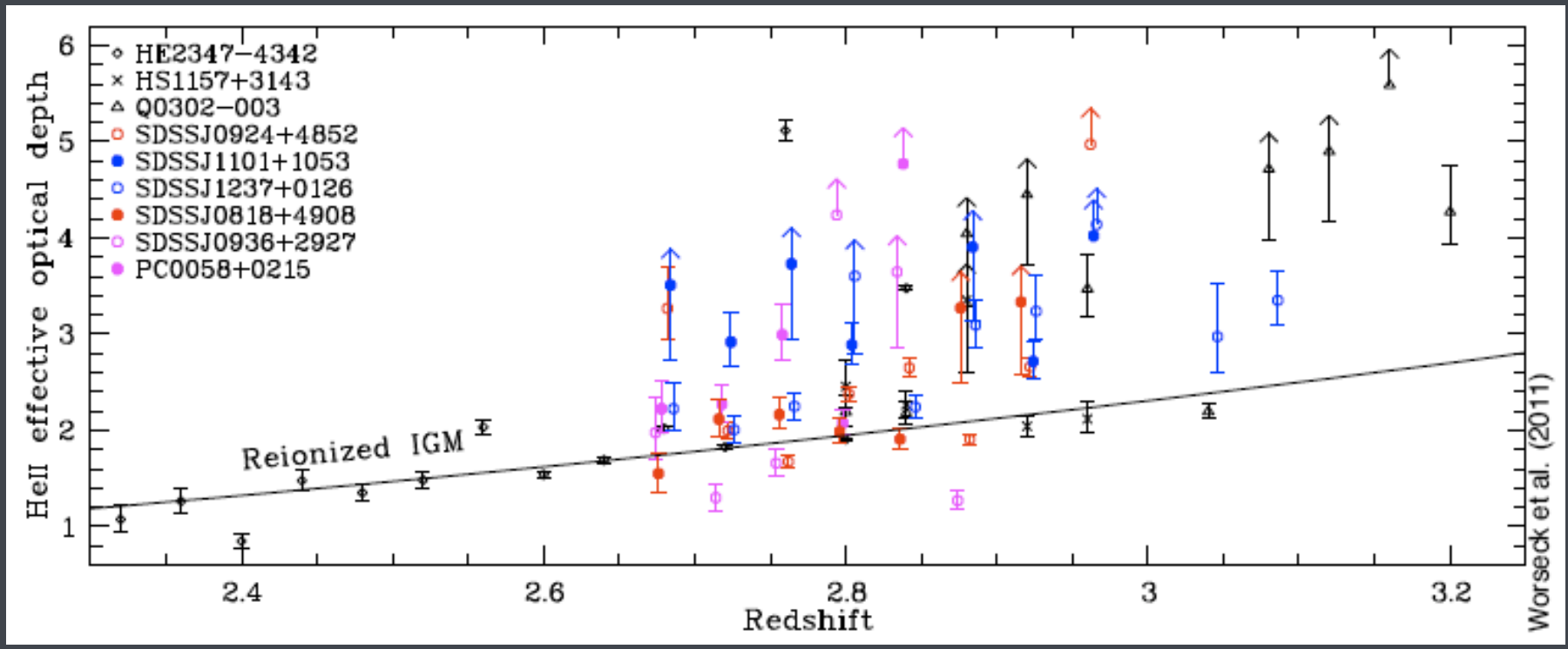


Scale matters!

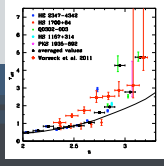




$\tau >> \tau_{avg}$ above z ~ 2.7



But also lower!



Large τ unlikely post-reionization

If $\langle\tau\rangle = 2$,

$p(\tau > 4) \sim 5\%$

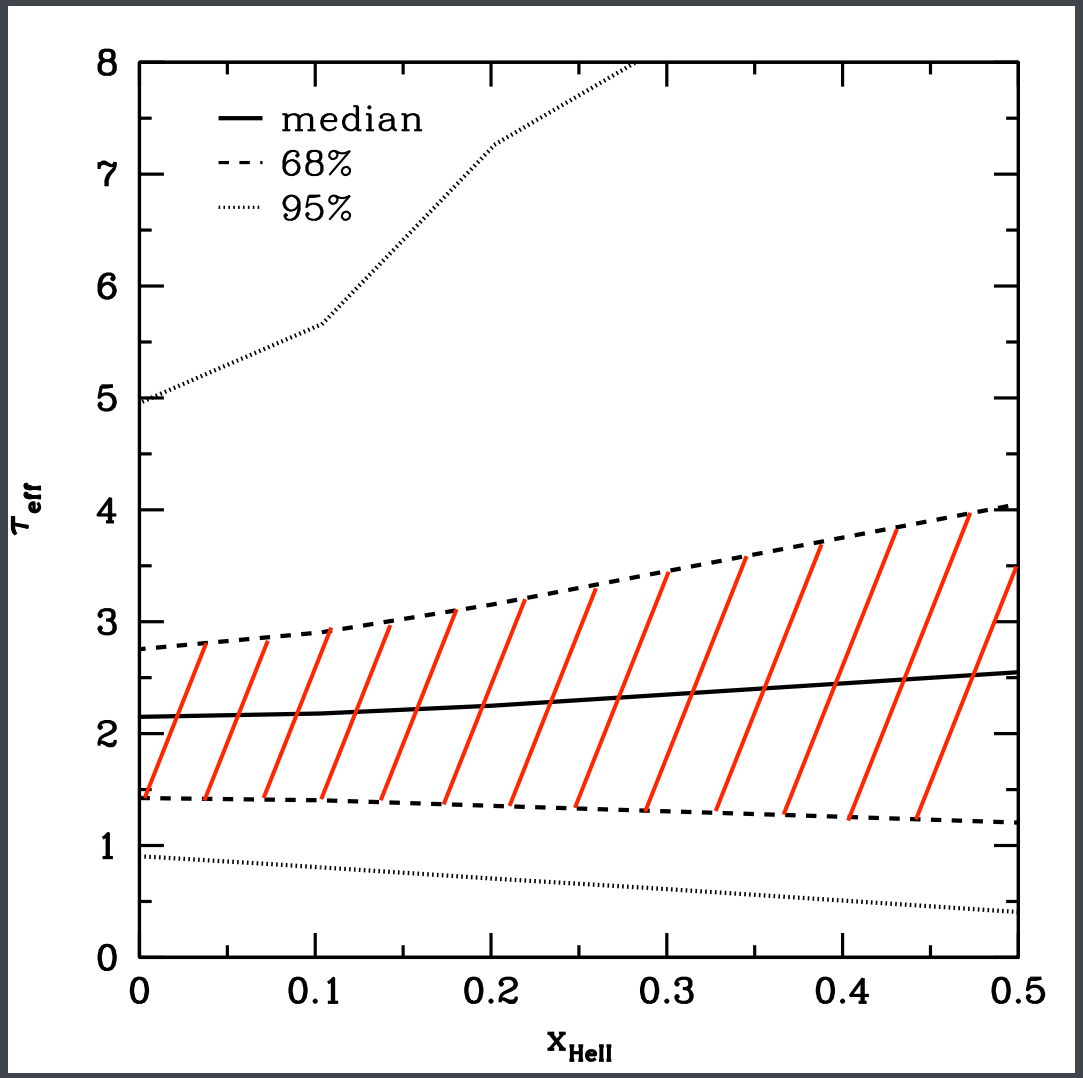
post-reionization

$p(\tau > 4) \sim 14\%$

$x_{HeII} = 0.20$

Spread increases during reionization

KD, Furlanetto (2013)



Conclusions and summary

Consensus forming for z_{reion} ~ 2.8

Post-reionization:

- Expect significant fluctuations in τ and Γ
- Large segments of low transmission unlikely

During reionization:

- Greater fluctuations in τ and Γ
- High opacity measurements more likely

Present and future:

- Many more COS lines of sight
- Other metal lines, proximity effect, heating…